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How many nurses do we need? A review and discussion of operational research techniques applied to nurse staffing

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ABSTRACT

Despite a long history of health services research that indicates that having sufficient nursing staff on hospital wards is critical for patient safety, and sustained interest in nurse staffing methods, there is a lack of agreement on how to determine safe staffing levels. For an alternative viewpoint, we look to a separate body of literature that makes use of operational research techniques for planning nurse staffing. Our goal is to provide examples of the use of operational research approaches applied to nurse staffing, and to discuss what they might add to traditional methods.

The paper begins with a summary of traditional approaches to nurse staffing and their limitations. We explain some key operational research techniques and how they are relevant to different nurse staffing problems, based on examples from the operational research literature. We identify three key contributions of operational research techniques to these problems: "problem structuring", handling complexity and numerical experimentation.

We conclude that decision-making about nurse staffing could be enhanced if operational research techniques were brought in to mainstream nurse staffing research. There are also opportunities for further research on a range of nurse staff planning aspects: skill mix, nursing work other than direct patient care, quantifying risks and benefits of staffing below or above a target level, and validating staffing methods in a range of hospitals.

What is already known about the topic?

- There is a long history of tools for setting nurse staffing levels.
- There is also a large body of evidence showing the importance of having sufficient nursing staff.
- However, there is still no agreement on how to set safe staffing levels in practice.

What this paper adds

- This paper highlights some key shortcomings of traditional nurse staffing methods: a lack of clarity around what decisions each tool supports and what "optimality" means, ignoring complexity (e.g. skill mix, uncertain workload and supply), and lack of validation
- Then our review identifies three corresponding contributions of operational research techniques applied to nurse staffing problems: "problem structuring", mathematical models that handle complexity, and numerical experimentation.
- The limitations of the operational research papers include that they provide local rather than general solutions, and models are not readily available for re-use.

1. Introduction

Inadequate nurse staffing levels have been implicated in hospital failures by inquiries and reports, which have found that many hospitals with high mortality rates have significant problems with nurse staffing levels. That achieving sufficient nurse staffing levels is important to patient outcomes and safety has been established through research studies. Several systematic reviews of research have concluded that higher registered nurse staffing levels are associated with lower risks of in-hospital mortality, shorter lengths of stay and fewer occurrences of other adverse patient events (e.g. Griffiths et al., 2016; Kane et al., 2007; Shekelle, 2013). The association between nurse-to-patient ratios and in-hospital mortality was confirmed in a large-scale cross-sectional study based in Europe (Aiken et al., 2014). Detailed investigations

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into adverse care outcomes have also noted a link (e.g. Keogh, 2013; Francis, 2013) although proving a causal relationship between increased nurse staffing levels and improved patient outcomes has been more challenging to academic researchers. However, evidence for causality is emerging through careful assessment of the results of a meta-analysis (Kane et al., 2007), longitudinal studies (Griffiths et al., 2018a; Needleman et al., 2011) and more direct evidence of a causal pathway (Ball et al., 2017; Griffiths et al., 2018b). Although the size of the effect remains uncertain (Griffiths et al., 2016), the research evidence indicates that maintaining sufficient nurse staffing levels is critical for patient safety.

There are many tools available for planning nurse staffing levels as highlighted by reviews in the health services literature (Fasoli and Haddock, 2010; Hurst, 2003). Whilst the research examining the association between nurse staffing and patient outcomes is plentiful, there is a lack of consensus on what staffing levels are acceptable in different situations, and how they should be planned. The National Institute for Health and Care Excellence prepared guidance on levels needed for safe staffing on acute adult wards in the United Kingdom, but concluded that there is insufficient evidence to recommend particular levels (National Institute for Health and Care Excellence, 2014). Estimates for cost-effectiveness of increasing registered nurse staffing levels are inconsistent due to differing staffing-mortality effect sizes, settings and cost perspectives used in economic models (Griffiths et al., 2016). The vast majority of studies provide overall hospital level associations and hence determining optimal nurse staffing levels (for safety and value-for-money) to be deployed on wards for different specialities remains an open challenge. Despite a vast literature on tools to determine staffing requirements, few concrete conclusions can be drawn about their accuracy or cost-effectiveness (Fasoli and Haddock, 2010).

In this paper we consider work from the discipline of *operational research* (called *operations research* in the United States of America). We hope that it can contribute to tackling the enduring problem of determining nurse staffing levels needed, given the challenges in applying the research evidence to practice and limitations of "traditional" methods for planning nurse staffing. Operational research is the "*discipline of using models, either quantitative or qualitative, to aid decision-making in complex implementation problems*" (Monks, 2016). It includes a set of techniques that are designed to produce optimal solutions to problems in the face of multiple sources of variation. Some examples of operational research techniques are optimisation, simulation, queuing theory and system dynamics. Operational research models have been widely applied in healthcare, e.g. for deciding where to locate ambulances (Ingolfsson et al., 2008), designing screening programmes (Ayer et al., 2015) and deciding appointment times (Gupta and Denton, 2008). In order to gain a general overview, readers may wish to refer to broad reviews of operational research applications in healthcare (Günal and Pidd, 2010; Hulshof et al., 2012).

Our paper aims to describe and determine how operational research techniques could contribute to planning nurse staffing, building on both the research evidence base on nurse staffing and outcomes, and the "traditional" approaches to planning nurse staffing. We start by briefly describing the traditional approaches, and then present a narrative review of the operational research literature.

2. Traditional approaches to planning nurse staffing

Nursing managers must decide how many nursing staff to *employ* (referred to as the *nursing establishment*) and how many nursing staff to *deploy* each shift. These are separate but inter-related decisions, which rely on being able to quantify nursing *workload*. There is a long history of methods to determine appropriate nurse staffing levels; an early study published in 1922 looked at how much nursing work was done by students and graduate nurses in New York City hospitals (Lewinski-Corwin, 1922).

A wide variety of approaches have been described although many approaches share similar characteristics. Telford's professional judgement method, which was first formally described in the United Kingdom in the 1970s (Telford, 1979), provides a way of converting the shift level staffing plan, decided using expert opinion, into the number of staff to employ. *Nurse-patient ratio* approaches assign a minimum or fixed number of nursing staff per occupied bed (Hurst, 2003) and minimum nurse-patient ratios have been mandated in several regions (Royal College of Nursing, 2012). These approaches assume that all patients have similar requirements for care, or that the average is stable across patient groups, so needs can largely be anticipated and met with a set roster. Thus these approaches tend to set a minimum level with an explicit or implied expectation that any additional staffing requirements be determined when demand increases.

Approaches that seek to account for individual patient variation in need can be used as alternatives to, or in conjunction with, mandatory minimums. *Patient classification systems* group patients according to their nursing care needs and assign a required staffing level for each (Fasoli and Haddock, 2010; Hurst, 2003). These use either pre-existing categorisations, e.g. diagnosis-related groups (Fasoli and Haddock, 2010), or bespoke categorisations, e.g. classifications based on levels of acuity and / or dependency groups (The Shelford group, 2014). In the *timed-task approach*, a detailed care plan, consisting of tasks that are assigned a recommended length, is constructed for each new patient based on that patient's care plan or a standard care protocol (Hurst, 2003). In all cases, the total staffing required is based on the sum of individual patient requirements. *Regression*-based approaches model the relationship between patient-, ward- and hospital-related variables, and the establishment, in adequately-staffed wards (Hurst, 2003). To obtain the recommended establishment for a particular ward, coefficients derived from the regression models are used to estimate the required staffing based on a number of factors.

The decisions that can be supported by each tool are usually not explicitly stated. Given the connection between employment and deployment decisions, it is sometimes unclear to what extent staffing methods can be applied to both. For example, the Safer Nursing Care Tool, which is widely-used in the United Kingdom, was designed to support decisions about the total nursing establishment required on a ward (The Shelford group, 2014). More recently, its core acuity-dependency scoring system has been used to plan and review daily staffing levels, supporting deployment and real-time redeployment decisions, for example using the SafeCare system from the commercial rostering system provider Allocate (Allocate software, 2017). However the validity of using the tool in this way has not been tested, for example by assessing the agreement between the tool's recommendations and professional judgement of the nursing requirement for particular shifts or days.

2.1. Nursing workload

Hands-on (*direct*) patient care is only one aspect of nursing work. In most systems, an estimate of the relative amount of other work (for example *indirect* care and managerial work) is applied as a constant uplift to the total direct care requirement (Hurst, 2003), whilst some make estimates at the patient level. For example, the RAFAELA system assesses the "planning and coordination of nursing care" required for each patient (Fagerström et al., 2014).

A significant difficulty when planning staffing is the uncertainty around future workload. The methods described above often match staffing levels to the average (mean) demand. This averaging can be compounded at multiple levels (e.g. average patient census, average need per patient and average time taken to deliver care for a patient with a given set of needs). When workload distributions are approximately (statistically) normal and have small standard deviations, using the mean may be an appropriate basis for planning since the required care will usually vary from the mean by a relatively small and known amount (for a normal distribution, 99.7% of values are within 3 standard deviations of the mean). Assuming some degree of flexibility in the work capacity of a given group of staff, most patients' needs might be safely accommodated most of the time. While some systems are explicit about an acceptable degree of variation from the mean (e.g. the RAFAELA system), this is rare, and the impact on safety of small deviations has not been widely researched. Little data is available to assess the extent or shape of distributions of time needed to care for individuals within given categories but substantial variability and highly skewed distributions seem plausible. Certainly left-skewed ward occupancy distributions have been reported (Davis et al., 2014) which would tend to generate mean staffing requirements that are lower than the median, leading to relative under-staffing more than 50% of the time.

2.2. Factors affecting the coverage of workload

The proportion of the total nursing staff that are registered nurses is referred to as *skill mix*. Given the significant evidence base that emphasises the specific association between registered nurse staffing levels or skill mix and outcomes (e.g.Aiken et al., 2017) it is perhaps surprising that skill mix is rarely addressed directly by traditional staffing methods (Buchan et al., 2001). This may be because many systems and approaches have their origins in settings where the contribution of support staff to direct patient care was relatively slight, e.g. the United States of America (Aiken et al., 2017). The issue of determining skill mix is compounded by the fact that nursing support staff roles can vary widely (Kessler et al., 2010). Some tools consider only registered or licensed nurses while others, such as the Safer Nursing Care Tool (The Shelford group, 2014), plan the total nursing team size and defer the skill mix decision to professional judgement.

For tools which aim to determine the staffing establishment, a constant uplift is typically applied to allow for leave, including annual and sick leave (Hurst, 2003). The timed-task and Telford approaches explicitly plan for breaks, while other methods implicitly assume that breaks will be the same as in the wards whose data were used to develop them or that any breaks are not part of the paid hours that are recommended. Whilst handovers between shifts are planned for in the Telford method, it is less clear if and how the other tools account for them, even though the amount of time required for handovers varies according to local practices, including shift patterns used (Griffiths et al., 2014).

2.3. What does "optimal" staffing mean?

Each staffing method makes an underlying assumption about what constitutes "adequate", "safe" or "quality" staffing, although these are often implicit. The staffing to deliver the "right" frequency and length of nursing tasks in the timed-task approach, and the "right" amount of care per patient in the nurse-patient ratio approach must be decided upon. These parameters are obtained either from expert judgement or from observations of care provided or from existing establishments, ideally in settings deemed to meet some quality criteria (Hurst, 2003). The quality threshold is not always made explicit. A number of reviews covering a large volume of research from several decades have provided little robust evidence about the tools' abilities to match nurse staffing to patient need, and none directly demonstrating an impact on outcomes or quality of care from using the tools to determine the required staffing (Fasoli and Haddock, 2010; Griffiths et al., 2016).

An alternative approach might be to compare care quality and resultant patient outcomes when staffing matches the level prescribed by the tool with quality and outcomes when it is below. Such evidence is also scant. There is evidence that staffing adequately according to the RAFAELA tool is associated with reduced mortality when compared to inadequate staffing (Junttila et al., 2016). However, the results showed that mortality was further reduced by staffing at higher levels than the tool suggests, which raises questions about how "optimal" staffing is defined here. Another study using the same tool suggests that there is a marginal improvement in the ability to predict outcomes when using mismatch between actual staffing levels and the assessed staffing requirement when compared to absolute staffing measures based on nurse to patient ratios (Fagerstrom et al., 2018).

Given the limitations of these tools and health services literature related to nurse staffing, we now move on to consider in more detail studies that have used operational research approaches. This is a separate body of literature and way of approaching decisions regarding nurse staffing which has been largely absent from existing reviews or discussion of nurse staffing, the levels needed and methods to plan.

3. Operational research approaches to planning nurse staffing

We adopted the following search strategy to find operational research papers on planning nurse staffing. On the 24th July 2017, we searched three databases, Scopus, Medline and the Cumulative Index of Nursing and Allied Health Literature, to find a representative sample. We searched in keywords, titles and abstracts (see Table 1 for search terms). We chose the *technique* search terms by considering common operational research techniques, identifying related Medical Subject Headings and removing search terms that generated mainly irrelevant results. Exclusions on the nursing types (*context*) were carried out at the abstract review stage. The *problem* search terms were chosen by examining expressions in relevant review articles and Medical Subject Headings, as well as including synonyms. The next stage

Table 1
Search Terms.

Techniques	Context	Problem
agent-based, computer simulation, discrete#event#simulation, heuristic, management science, Markov, newsvendor, non-Markov, operational research, operations management, operations research, optimi?ation, programming, queu#ing, stochastic, system dynamics Medical Subject Headings: computer simulation, decision support techniques, mathematics, systems analysis/operations research	Nurse, nursing	employed nurses, manpower planning, nurse allocation, nurse schedul*, nurse staffing, skill-mix, staff allocation, staff planning, staff schedul*, workforce planning, workforce requirements Medical Subject Headings: Nursing/Manpower, Personnel Staffing and Scheduling

was an abstract review and where necessary full text skim to check for relevance. The inclusion criteria were: full text is accessible, concerns nursing staff working in general inpatient units, uses an operational research technique and provides a mathematical model to support a nurse staffing decision in a unit (ward) or hospital(s).

After deduplication, 535 papers were found; 153 were deemed relevant after the abstract review of which 27 papers were considered in depth. The other 126 papers all address the so-called Nurse Rostering Problem and rather than presenting these individually, we have drawn primarily on existing review papers to identify the key points (Burke et al., 2004; De Causmaecker and Vanden Berghe, 2011).

We categorised the 27 papers based on whether their primary purpose relates to employment, deployment, integrated employment-deployment, or factors that affect workload. The categorisation suggested by the first author was validated by another author with initial agreement on 78% of papers. Disagreements were resolved by consulting a third author. See Supplementary material Tables 2–5 for details about the papers.

Employment decisions include how many permanent staff to employ, what budget to set for staff costs, and policy decisions relating to the composition of the nursing workforce. These are usually long-term decisions made at the hospital or unit level. *Deployment* decisions are made in the medium- or short-term, usually for single units or for multiple units when nurse sharing is considered. Examples are how many staff are needed to work each shift, adjustments for adapting to demand fluctuations and assigning staff to patients.

3.1. Nurse staffing problems: examples of relevant operational research techniques

Here we discuss the application of operational research techniques to nurse staffing problems in the papers we reviewed. The operational research techniques used include optimisation (24/27 papers), simulation (6/27 papers), queuing theory (3/27 papers) and forecasting (1/27 papers). The full details of which techniques are used in each paper are provided in Supplementary material Tables 2–5. Notably, these papers are, with the exception of Brusco et al. (1993), published in operational research or management science journals rather than in the nursing literature, so form a distinct body of work.

Employment decisions are commonly framed as optimisation problems, for example calculating the optimal number of nursing staff to employ such that costs are minimised and assuming that unmet demand for nursing (measured e.g. by a minimum nurse-patient ratio) is satisfied by using float or external staff (Harper et al., 2010; Maass et al., 2017). Other operational research techniques applied to employment decisions are forecasting future demand (Mincsovics and Dellaert, 2010) and simulating the likely range of demand for nursing staff by grade each day (Harper et al., 2010).

Likewise deployment decisions are predominantly addressed by optimisation approaches. For example the Nurse Rostering Problem can be formulated as how best to assign nursing staff to shifts so that staff satisfaction requirements and work regulations are met (Burke et al., 2004). While the traditional nurse staffing literature identifies how many nursing staff to employ and deploy, the rostering problem deals with the gap between these two – scheduling the employed nursing staff on shifts. Here the optimal solution may be defined as the best match to workload, most stable, fair, flexible or cheapest roster, or some combination of these. The large number of possible rosters means this problem is prohibitive to solve using exact methods (methods that give the true optimal solution). Instead, heuristics (methods that aim to find a good but not necessarily the best solution in a reasonable time) may be built into commercial rostering systems. Deployment papers also use simulation, for example alternative policies for assigning nurses to patients are compared in a simulation (Sundaramoorthi et al., 2010).

The papers that address employment and deployment decisions jointly (Li et al., 2007; Venkataraman and Brusco, 1996) both use optimisation. Venkataraman and Brusco (1996) evaluate the cost impacts of nurse staffing policies when employing and deploying staff. Li et al. (2007) provide integrated optimisation models that generate both recommended numbers of staff to recruit and dismiss, as well as daily numbers of staff working.

Finally, three of the papers we considered address the more fundamental question of what factors affect nursing workload (De Véricourt and Jennings, 2011; Sir et al., 2015; Yankovic and Green, 2011). The factors considered are occupancy (De Véricourt and Jennings, 2011; Yankovic and Green, 2011), the length and frequency of nursing tasks (Yankovic and Green, 2011), unit size (Yankovic and Green, 2011), length of stay (Yankovic and Green, 2011), individual nurses' skills (Sir et al., 2015) and patient acuity indicators (Sir et al., 2015). Two of these papers use queuing theory; one considers patients waiting to be attended to by a nurse (De Véricourt and Jennings, 2011) and the other additionally considers patients waiting for a bed (Yankovic and Green, 2011). The queuing theory approaches here highlight an issue that is neglected in many traditional methods, especially timed-task based approaches. Total demands for nursing care might be predictable on average, but patients' needs can be emergent and do not tend to neatly distribute themselves across a shift. Admissions, meals, administration of medications, emergencies and requests for information all operate on different schedules (or no schedule at all) and nurses can easily face multiple demands at the same time.

3.2. Why are operational research methods helpful here?

The key contributions of operational research methods to the nurse staffing problem seem to be their "problem structuring" element, their ability to handle complexities, and opportunities for numerical experimentation.

Firstly, at the beginning of an operational research project it is usual to spend a substantial amount of time on *problem structuring,* that is, deciding what aspects are in and out of scope, deciding on assumptions and explicitly defining the problem under study, before identifying appropriate techniques. Traditional nurse staff planning methods tend to conflate the different elements of the problem (employment, deployment, and measuring workload), while operational research papers have separated out these interrelated issues and been clearer about which are being addressed. For example, operational research models developed to determine the number of staff to employ are often valid regardless of which workload measure (e.g. nurse-to-patient ratio, or an acuity tool) is used. They are usually also clearer about the timescale of decisions that their models can address. Unlike traditional methods, which define appropriate staffing implicitly (e.g. enough staff for safety), it is standard practice for operational research papers to explicitly define *performance measure(s),* which are used to evaluate alternative decision options. Often, the objective of these models, in particular for the employment and budgeting models, is to minimise financial cost, while still meeting some target staffing level. Further examples of performance measures used particularly in deployment relate to covering workload, balancing workload between nurses, and satisfying nurse preferences. Two of the workload measures papers aim to find the number of nurses needed so that the chance of patients waiting an excessive time for care is limited.

Secondly, operational research approaches have provided ways of dealing with the complexities that have been absent from traditional methods.

For example, variation in the demand for nursing care over time is largely ignored in the mainstream literature and approaches to planning staffing. In contrast, many operational research papers consider time-dependent demand, for example monthly patterns. Demand uncertainty is often modelled by statistical distributions or other probabilistic methods, rather than using the average rates common in traditional tools. Harper et al. (2010) found that planning for average demand underestimates the permanent staff needed to minimise cost (while still meeting target staffing levels), compared to considering demand fluctuations. Similarly, time patterns in supply e.g. month-dependent absence rates, as well as supply uncertainty have been considered by some models.

Traditional staffing methods do not account for different nursing contract types: employed permanently on a ward, part of a float pool that can be allocated among wards, or temporarily hired, for example from an internal bank or from an agency. However, all the operational research papers using cost as the performance metric consider them, since float and temporary staff tend to be more expensive and potentially less efficient.

The operational research papers offer various ways to model skill mix that are missing from traditional methods. Studies considering patient-nurse assignment recognise that task lengths may vary depending on staff skills (Punnakitikashem et al., 2013; Sir et al., 2015; Sundaramoorthi et al., 2010). Some papers distinguish between experienced and inexperienced staff, whose efficiencies improve as they are trained (Abernathy et al., 1973), or who can perform tasks at their skill level and lower, but not above (Li et al., 2007). Harper et al. (2010) use a workload measure that specifies the direct care ratio for each nurse grade. Moving from an estimate of need based on average nurses per bed or acuity ratios their PROMPT model simulated dynamic changes over the year. They found that there should be more staff in the middle pay bands at their case study departments, with the optimisation model showing that additional permanent staff reduced overall costs by lowering agency spend.

In some operational research models, the risks associated with under-staffing or temporary staffing, and the benefits of staffing above the target staffing level, called “over-staffing”, are included as performance measures (Abernathy et al., 1973; Davis et al., 2014; Maass et al., 2017; Mincsovics and Dellaert, 2010; Paul and MacDonald, 2014). Although reliable parameter estimates for these measures are lacking, this approach highlights an implicit assumption of the approaches that simply set staffing at a mean level: that risk is symmetrical and that over-staffing either cancels out the risk of under-staffing or else represents an equivalent risk to be avoided. Such assumptions are rarely tested and findings such as that of Junttila et al. (2016) show that so called “over-staffing” may in fact be associated with benefits to patients including a reduced risk of death.

Thirdly, it is common for operational research papers to contain the results of numerical experiments. These may involve systematically varying parameters to show applicability to different situations, comparing policy options, testing the impact of controllable parameters on performance, or testing the impact of uncertain, uncontrollable parameters on performance (*sensitivity analysis*). A strength over traditional methods is that operational research models can be used to evaluate the potential effects of staffing changes before implementation. Half of the employment papers compare their staffing recommendations’ modelled performance to actual or estimated current performance, and two further papers test against real life (Davis et al., 2014; Sir et al., 2015). It is striking that aside from the small number of papers that estimate the costs and benefits of staff changes based on coefficients derived from cross-sectional studies of association with outcomes (e.g. Shamliyan et al., 2009; Twigg et al., 2015), there is little evidence linking use of traditional methods for planning staffing with either costs or the quality of care. However, nurse-sensitive patient outcomes were not considered in the operational research papers either.

4. Conclusion and discussion

In conclusion, the operational research literature complements the mainstream literature on nurse staffing and planning methods in a number of ways. While traditional nurse staffing methods sometimes conflate employment, deployment and workload assessment issues, and do not define what constitutes appropriate staffing, the operational research papers tend to be more explicit, in particular by specifying performance measures. The operational research papers examined provide methodological advances including planning for variable demand, modelling skill mix by using relative efficiencies, and models that aim to balance the risks and benefits of under- and over-staffing.

However, unlike many mainstream nurse staffing papers, the operational research papers do not provide parameters estimated from large-scale datasets (usually focusing on a few units or one hospital) so by themselves cannot provide general findings about the nursing workforce. A key limitation of the operational research models is that although many could be generally applicable, they are not readily available for re-use. The biggest success in terms of practical application seems to be the PROMPT simulation model designed for planning nursing establishments, which has been used in a number of hospitals (Harper et al., 2010).

Issues that could benefit from further research include skill mix, nursing work aside from direct care, quantifying risks and benefits of under- and over-staffing, and validating staffing methods across a range of hospitals. Operational research techniques could be brought in to help address these issues alongside traditional methods. The operational research approach can help structure the problem, deal with complexity and perform numerical experiments before implementation.

Future possibilities for nurse staffing research utilising operational research techniques include the following. Queuing theory models could be used to investigate how trainees and new staff roles such as nursing associates could affect both demand (training/supervision needs) and supply. Queuing theory could also be used to examine nursing work in more detail by separating urgent, non-urgent and discretionary tasks with prioritisation between patients. Such investigations could contribute to an emerging body of work that investigates links between nurse staffing and omissions, delays or rationing of care, which suggests that there may be conscious or unconscious decisions to prioritise some aspects of care in the face of excess demand (Griffiths et al., 2018c; Jones et al., 2015). Simulation models could be used to assess existing staffing tools (or compare alternative staffing tools) for setting establishments in terms of how they affect costs and daily staffing adequacy. In practice, hospitals could benefit from software that uses near real-time data to recommend how to adjust staffing levels to better match patient needs. Operational research techniques such as optimisation and simulation could be embedded in integrated rostering-deployment-employment systems to help make short-term and long-term staffing decisions. Thus operational research methods can help both with researching the impact of staffing levels and also with planning nurse staffing levels, two previously disconnected areas of endeavour.

We believe that it is time to bring in operational research to supplement traditional techniques for determining the best approaches to managing and maintaining safe nurse staffing

levels. Operational research capacity in health services research remains limited (Manzi et al., 2018), and it is notable that most of this significant body of work has been published in operational research journals with teams largely emanating from operational research or related background. We would therefore encourage active collaboration between operational research specialists in the field and those established nurse staffing research groups who have successfully delivered research involving gathering and analysing data at scale and across multiple sites.

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Appendix A. Supplementary data

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